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A LOW PRESSURE EXPANSION CLOUD CHAMBER

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(Received, December 17, 1960)

ABSTRACT. A pressure defined expansion cloud chamber has been constructed and operated satisfactorily up to total pressures of 5 cm of Hg. The best track conditions for different total pressures as a function of the expansion ratio have been determined and discussed using ethyl, *n*-butyl and iso-amyl alcohols as condensant vapour and argon as permanent gas. Photographs of Po^{210}-α tracks taken at 5 cm. of Hg with iso-amyl alcohol and argon mixture are presented.

1. INTRODUCTION

A low pressure cloud chamber finds special applications in the study of uranium fission and of other low energy interactions of heavy charged particles with matter. Where the ranges of the observed track lengths in a gas at atmospheric pressure in such interactions are so short that the track lengths are not measurable, advantage of the fact that lowering of pressure of the gas-vapour mixture in the active volume of the chamber "magnifies" the ranges of the particles has been utilised to get greater details of the interaction. Thus, Joliot (1934) has operated a low pressure cloud chamber in order to study the mechanism by which heavy ions, resulting from radioactive decay, lose their energy. R. G. Mills (1953) has used a mechanical expansion mechanism to actuate a low pressure cloud chamber and operated at pressures of 4.5 cm in the investigation of the stopping power of He and water vapour.

Operation of a cloud chamber at low pressures involves additional difficulties which are not in common with cloud chambers generally used over a wide range of pressures. Lowering of the initial pressure is achieved by reducing the partial pressure of the permanent gas. The gamma coefficient of the vapour-gas mixture becomes smaller and in order to obtain the necessary supersaturation for condensation of the vapour on ions higher expansion ratios are needed. At the same time lowering of the partial pressures of the permanent gas restricts the uniform diffusion of the condensing vapour on growing drops. This effect becomes important in the low pressure region as the vapour-gas mixture has a low heat capacity. The low heat capacity and the large temperature variations involved for obtaining the necessary supersaturation result in an intensive and fast heat exchange between the filling mixture and the chamber walls leading

to the lowering of the supersaturation and a consequent shortening of the sensitive time. For this reason a fast expansion mechanism is of extreme importance in the operation of a low pressure cloud chamber.

The higher expansion ratios needed to work the cloud chamber at low pressures as mentioned earlier introduces the undesirable effects of turbulence motion of the gas molecules within the chamber, thereby resulting in the distortions of the tracks. This situation can be avoided by a suitable choice of the gas-vapour mixture such that good quality of tracks can be obtained for a given pressure with a relatively smaller and conveniently reproducible expansion ratio. Further the choice of the gas-vapour mixture has a vital role to play with reference to the particular mode of operation in which we are interested. In all randomly operated cloud chambers operating at low as well as high pressures, water vapour or some form of alcohol is used as a condensant vapour, together with a non-condensible gas like air or argon. Since the cloud chamber is intended to be triggered by an internal counter controlled mechanism such that the desired events can be selected and photographed by suitably running an open counter in the proportional region (Hodson *et al.*, 1950), a selective choice of the gas-vapour mixture has to be made so as to make a compromise between obtaining good tracks and at the same time operating the counter within for the same gas-vapour filling. In counter operation the production of gas multiplication depends on the electrons remaining freely mobile and electron attachment must be avoided. For this reason oxygen and water vapour have been excluded and our choice has been narrowed down to the study of several alcohols as condensants and argon as the non-condensible gas.

This paper describes the constructional details of a pressure defined expansion cloud chamber. Results of an investigation on the adequate choice of the gas-vapour mixture for obtaining best track conditions at different initial total pressurs in relation to the expansion ratios are also presented.

2. CONSTRUCTIONAL DETAILS OF THE CHAMBER

The cloud chamber constructed is a pressure defined expansion chamber of the rubber diaphragm type and the assembly of the different components of the apparatus is shown in Fig. 1.

The front chamber which constitutes the active volume of the chamber is made of a perspex cylinder 10 inches i.d. and 2 inches in height, the wall thickness being 1/4 inch. A circular glass plate 1/2 inch thick covering the top of the perspex cylinder forms the window of the main chamber which faces the camera mounted vertically upwards for taking stereoscopic pictures. A thin rubber diaphragm 1/32 inch thick isolates the main chamber volume from a pan-shaped back chamber made of copper. The back chamber is separated from the vacuum ballast having a volume approx. 10 litres by means of an expan-

sion valve which is normally closed under gravity. The expansion valve used is an Edwards 1 inch bore high vacuum magnetic isolation valve operated on 200 volts D.C. The connecting links between the chamber and the inlet of the expansion valve and that between outlet of the expansion valve and the ballast are copper pipes of short lengths 1 inch in diameter. The vacuum ballast is evacuated by means of a Cenco high vacuum pump and maintained roughly at 10^{-3} mm of Hg. which is the limiting pressure of the pump.

Initially the back chamber is maintained at a pressure slightly higher than that in the main chamber, such that the rubber diaphragm is blown forward against the perforated disc, thereby diminishing the active volume of the main chamber. Expansion is initiated by energising the magnet, and when the magnet valve opens, the sudden release of pressure in the back chamber by getting a direct communication with the vacuum ballast forces the rubber diaphragm downwards until it comes to rest against the perforated backing plate. This sudden change in the relative positions of the rubber diaphragm followed by a corresponding change in the volume of the main chamber causes the expansion of the gas in the main chamber volume and undergoes an adiabatic cooling. The adjustment of the amount of the expansion is controlled by changing the position of the backing plate. The backing plate is made of 3/32 inch brass plate with a number of uniformly spaced 1/8 inch drill holes all over and is rigidly

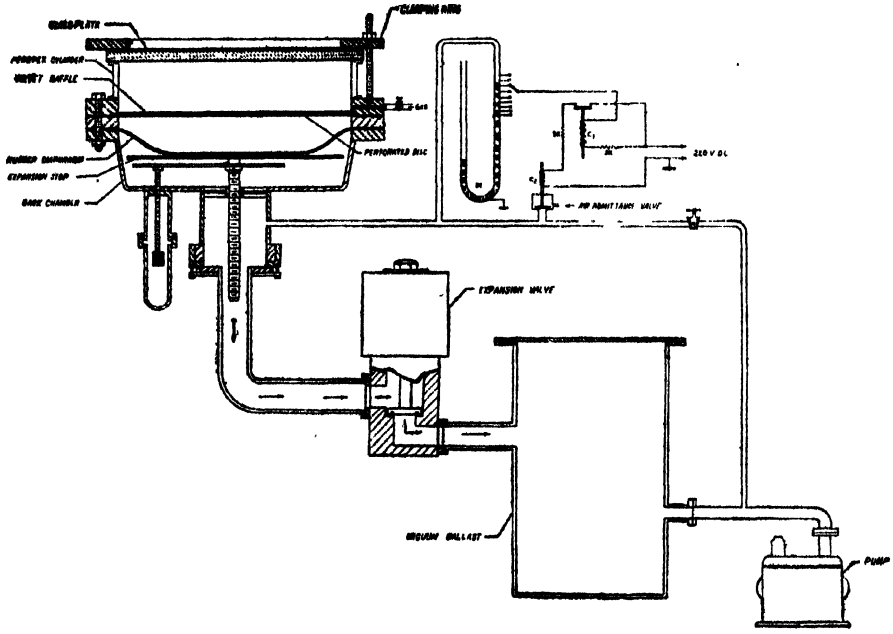

Fig. 1. Constructional details of the cloud chamber.

screwed on to a threaded rod capable of vertical motion in the back chamber. The motion of this rod can be conveniently regulated from outside, without

any major dismantling of the components of the apparatus, by means of a mutually coupled gear system as shown in Fig. 1. The perforated disc at the top is similar to the one at the bottom and is covered with a screen wire mesh which is faced with a black velvet cloth to form a uniform photographic background. The drill holes in the top plate together with the wire mesh and the pores in the velvet will define the stream lines of motion of the gas and reduce the turbulence of the gas molecules when the rubber diaphragm is being pulled down so that the tracks are free from distortion.

The underside of the glass plate is coated with a ring of Aquadag to make the surface electrically conductive. A sweep field of +45 volts is applied between this coating and the base of the chamber, which serves to remove the background ions produced by the tracks during the preceeding expansion. For illumination of the tracks, two Mazda flash tubes, F.A.2 rated at 500 Joules are used. Two banks of condensers each 64 μF normally charged to 2000 volts are discharged through the flash tubes by a spark coil. The spark coil is triggered by discharging a small condenser through the primary of the coil. Cylindrical lenses are used to collimate the light from the flashing units, into a parallel fan-shaped beam limited in height by diaphragms in order to avoid direct light reaching the top and the bottom of the chamber.

3. AUTOMATIC PRESSURE CONTROL DEVICE

The equipment shown at the right hand top of Fig. 1 is an automatic device for setting back the pressure in the back chamber to the same desired level after every expansion. The mechanism can be understood as follows: As soon as the magnet valve opens, expansion of the chamber takes place and there is a lowering of the back chamber pressure owing to its communication with the ballast which is maintained at a sufficiently low pressure. A little later the magnet current is short circuited by closing a relay included in the electronic sequence arrangement (not shown here) which returns the valve to its normal position and thus isolating the back chamber from the vacuum ballast. Simultaneously, the pressure difference in the back chamber is communicated to a mercury manometer M, through an auxiliary connection, taken from the bottom of the chamber. There are a number of contact points of tungsten fused into the right hand limb of the manometer at regular intervals and by changing the point of contact; the pressure in the back chamber can be cut off at discrete levels. In the present position of the mercury level as indicated in the manometer representing the state of affairs immediately after expansion, the relay coil C_1 is energised and the relay is pulled down, thus interrupting the current in the coil C_2 of the air admittance valve. This valve is the Edwards magnetic air admittance valve 1/16 inch bore, maintained closed magnetically against a spring which opens the valve to atmosphere when the current is switched off.

Thus, when the current in the magnet coil is switched off air is admitted through the valve into the back chamber and simultaneously the mercury level in the manometer is pushed down to a level just below the variable contact point. At this stage the relay coil C_1 is de-energised and the current path for the air admittance valve is restored thus closing the magnet valve and preventing any further admittance of air.

In practice, however, after running for several days a thin conducting coating is formed on the inner glass walls of the mercury manometer owing to impurities in the mercury so that the spacing between the several variable contact points is electrically bridged up and the purpose of discretely cutting off the pressures is not achieved. This is avoided by cleaning the tungsten contacts and also rinsing the manometer with dilute Hydroflouric acid and also filtering the mercury at intervals.

4. RESULTS AND DISCUSSION

The main chamber was completely evacuated initially and simultaneously the back chamber was also evacuated to prevent implosion of the rubber diaphragm. 5 c.c. of dehydrated alcohol was injected into the main chamber and the desired total pressure in the working chamber has been set up by introducing argon whose flow is regulated by a needle valve. The total pressures in the main chamber are recorded by means of a mercury manometer, connected to

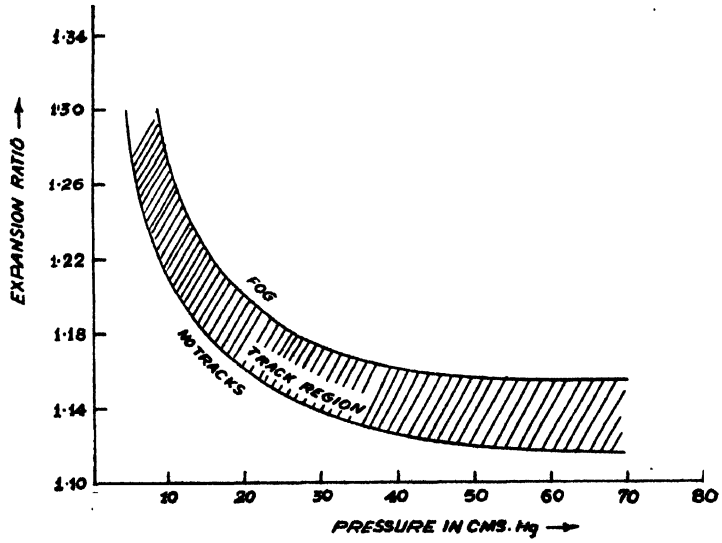

Fig. 2. A typical curve showing the variation of expansion ratio with initial total pressures for any alcohol showing the ion and cloud limits. This particular curve is that for iso-amyl alcohol.

the main chamber, not shown in Fig. 1. The expansion ratio, defined as the ratio of the initial to the final pressures, has been adjusted by defining the position of the stopping plate. The best track conditions were visually and photo-

graphically determined for different initial total pressures, each time the desired total pressure being built up by leaking in argon into the working chamber.

Fig. 2 presents the variation of expansion ratio with total pressures obtained for iso-amyl alcohol and argon.

The shaded area represents the region of track formation. The best track conditions, however, lie close to the lower boundary of this region. As we go towards the interior of this region and away, the tracks are masked with a background fog and the quality of tracks deteriorates. Observations have been carried out with different alcohols with a view to choose a suitable gas-vapour mixture for operating the chamber at very low pressures with conveniently reproducible expansion ratios. The results of investigation obtained with ethyl, *n*-butyl, iso-amyl alcohols are shown in Fig. 3 and in each of these curves only the best track conditions are presented.

In the above series of experiments Po^{210}—α tracks were visually observed and photographed at different pressures. The source in the form of a foil prepared in the laboratory from used randon needles is mounted on a perspex base and supported inside the chamber from the wall of the perspex cylinder.

The interpretation of the general trend of the curves can be better understood from the following considerations.

The supersaturation produced as a result of expansion is given as (Das Gupta and Ghosh, 1946)

$$S = \frac{p_1}{p_2}(1+\epsilon)^{\gamma} \qquad \ldots \quad (1)$$

Where $(1+\epsilon)$ is the expansion ratio p_1, p_2 are the saturation pressures at the initial and final temperatures.

γ = ratio of specific heats of the complex gaseous mixture in the chamber. If p_g and p_v be the partial pressures of the gas and vapour with the corresponding γ's, γ_g and γ_v, γ for the composite mixture is given by the formula due to Richarz (1906) as

$$\frac{1}{\gamma-1} = \frac{1}{\gamma_g-1}\cdot\frac{p_g}{P} + \frac{1}{\gamma_v-1}\cdot\frac{p_v}{P} \qquad (2)$$

where P is the total pressure equal to (p_g+p_v).

It is seen from equation 2 that when the total pressure P is decreased by diminishing the gas pressure p_g, p_v/P increases while p_g/P remains practically the same for $p_g >> p_v$ as a result the value of γ decreases. For a given expansion ratio the fall of temperature is therefore less and the supersaturation produced smaller. Thus, one needs a higher expansion ratio to attain the same degree of supersaturation. The curves plotted in Fig. 3 for the best rack conditions with different alcohol vapours show a functional dependence of the expansion ratio on the total initial pressures.

It is further observed by an intercomparison of the curves drawn for different alcohols that there is a finite dependence of the expansion ratio on the molecular weights of the alcohols involved. The heavier the alcohol, smaller is the expansion ratio needed to bring about the same degree of supersaturation for a

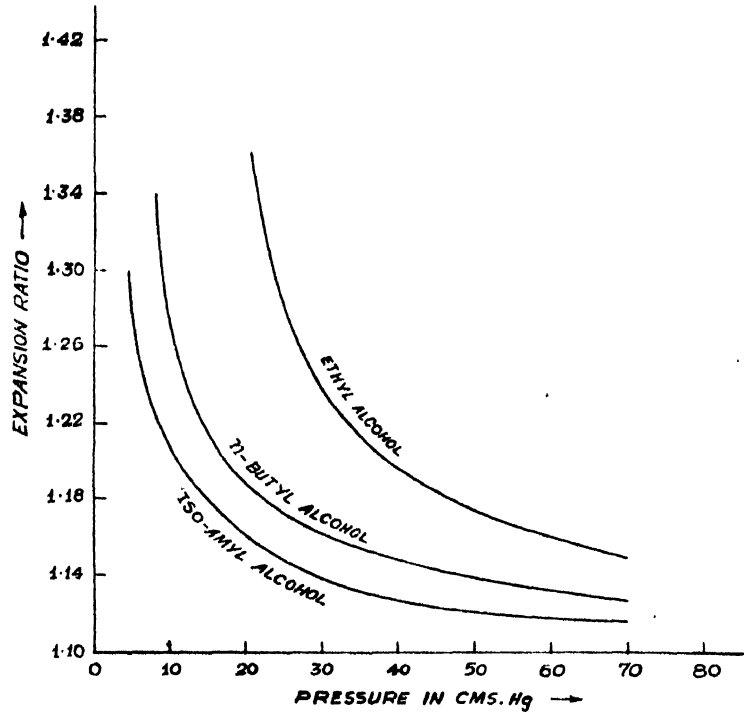

Fig. 3. Variation of expansion ratio with initial total pressures for best track conditions with different alcohols.

given pressure. Flood (1934) found that the value of supersaturation at the ion limit or cloud limit depends strongly upon the type of vapour used in the chamber. Thus, iso-amyl alcohol with a molecular weight 88.15 requires a much smaller expansion ratio than *n*-butyl alcohol whose molecular weight is 74.12.

It was shown by Powell (1928) that when the partial pressures of a condensible vapour becomes a large fraction of the whole pressure, many factors operate which restrict the growth of supersaturation. The supersaturation reached is much smaller than that deduced from adiabatic expansion. The effect is attributed to the evaporation of hot vapours from the free liquid surface in the chamber. Joliot (1934) has shown that the working expansion ratio increases from 1·305 at atmospheric pressure to about 2 when only saturated water vapour remains. It is thus apparent that the operation of a conventional cloud chamber with pure alcohols is a matter of considerable difficulty and the permanent gas plays an important role in its operation.

In the present set of observations it is seen that by using heavier alcohol, the initial total working pressure can be pushed down to lower pressures than with the lighter alcohols. In case of iso-amyl alcohol it is as low as 5 cm. This is perhaps on account of the fact that for a given total pressure, the vapour pressure contributed by the heavier alcohol is in a smaller proportion to the total pressure than for the lighter alcohols with the result that the permanent gas which is in considerable quantity plays its role for proper condensation at conveniently reproducible expansion ratios.

Fig. 4. A typical photograph of P_o^{210} – α tracks at 5 cm of Hg using iso-amyl alcohol and argon.

Fig. 4 shows a typical photograph of P_0^{210}—α tracks obtained at 5 cm of Hg using iso-amyl alcohol and argon as the filling mixture and the tracks can be seen stretched to lengths extending over the entire diameter of the chamber. Thus, the advantages of such magnified track lengths can be appreciated when one has to work with fission fragments or such other reaction products with low energy which have ranges of only few millimeters at atmospheric pressures.

ACKNOWLEDGMENTS

The author is indebted to Prof. B. D. Nag Chaudhuri, Director, Saha Institute of Nuclear Physics, for suggesting the problem and continued guidance through the progress of the work. Grateful thanks are due to Prof. D. N. Kundu for his helpful suggestions and discussions. In the earlier stages Mr. A. P. Patro was associated with the work, to whom thanks are also due.

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